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# How reliable are Hounsfield-unit measurements in forensic radiology?

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ABSTRACT

*Objective:* To assess the reliability of computed tomography (CT) numbers, also known as Hounsfield-units (HU) in the differentiation and identification of forensically relevant materials and to provide instructions to improve the reproducibility of HU measurements in daily forensic practice.
*Materials and methods:* We scanned a phantom containing non-organic materials (glass, rocks and metals) on three different CT scanners with standardized parameters. The *t*-test was used to assess the influence of the scanner, the size and shape of different types of regions-of-interest (ROI), the composition and shape of the object, and the reader performance on HU measurements. Intra-class correlation coefficient was used to assess intra- and inter-reader reliability.
*Results:* HU values did not change significantly as a function of ROI-shape or -size ($p > 0.05$). Intra-reader reliability reached ICC values >0.929 ($p < 0.001$). Inter-reader reliability was also excellent with an ICC of 0.994 ($p < 0.001$). Four of seven objects yielded significantly different CT numbers at different levels within the object ($p < 0.05$). In 6/7 objects the HU changed significantly from CT scanner to CT scanner ($p < 0.05$).
*Conclusion:* Reproducible CT number measurements can be achieved through correct ROI-placement and repeat measurements within the object of interest. However, HU may differ from CT-scanner to CT-scanner. In order to obtain comparable CT numbers we suggest that a dedicated Forensic Reference Phantom be developed.



## 1. Introduction

Over the last decade, computed tomography (CT) has become an important element in forensic investigations [1–4]. There is general agreement that CT is especially useful for the detection, localization and identification of foreign objects in corpses [5–7]. CT holds two important advantages over conventional radiographs: three-dimensional image reconstructions and the capability to quantify X-ray attenuation (i.e. the reduction of beam intensity as X-rays traverse an object) [8]. Attenuation is expressed in CT numbers, known as Hounsfield-units (HU) [9]. An increasing number of forensic studies rely on CT numbers for object identification and material or tissue differentiation [10–16].

However, little attention has been paid to the reliability and reproducibility of CT numbers. In practice, CT numbers are measured on cross-sectional CT images with a region of interest (ROI) [17]. CT numbers depend on measurement technique (ROI-, and observer-dependent factors), object composition (absorber-dependent factors), and beam energy (tube-dependent factors).

ROIs should never be placed on the rim of an object to avoid partial volume effect and must include more than one pixel (Fig. 1a) [18]. CT numbers will generally increase with density and diameter of the absorbing material [19]. Beam energy is defined by the X-ray tube voltage setting and is measured in peak kilo voltage (kVp) [8]. It is important to note that X-ray beams are a blend of photons with different energies (they are polychromatic) and the average beam energy is only about one third of the maximum beam energy (kVp) [8]. The exact beam composition will vary among CT scanners of different manufacturers and may also change over time. Early studies on the subject have reported scanner-dependent variability in CT numbers [20,21]. In order to compare HU measurements, differentiate materials or reliably identify foreign objects, it is of paramount importance to know how these different factors affect HU measurements.

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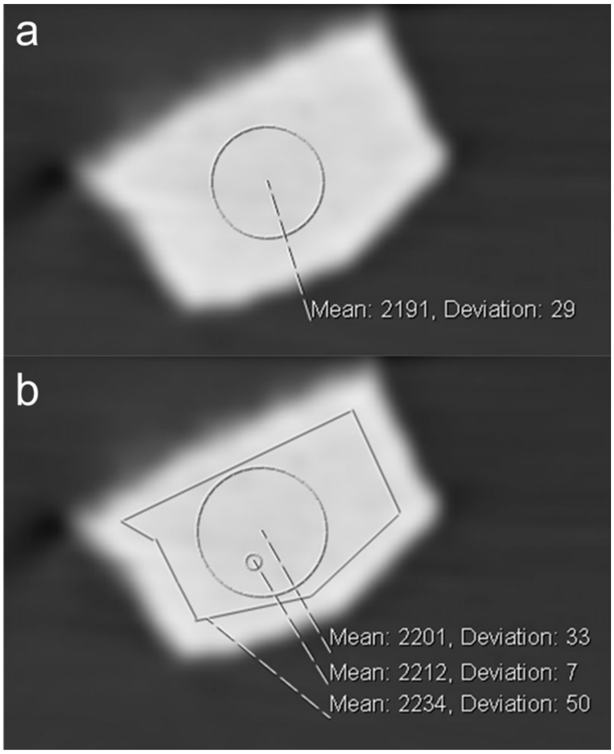


**Fig. 1.** CT image of sample material (block of quartzite). (a) To measure the CT number (i.e. the attenuation) of a material, the region of interest (ROI) should never be placed on the rim of an object to avoid partial volume effect and must include more than one pixel. (b) To assess the influence of ROI size and shape on HU measurements, measurements were repeated using three different types of ROI: a large circular ROI (size adapted to object diameters), a small circular ROI, and a non-circular ROI (size and shape adapted to the individual objects).

The goal of this study was to assess the influence of ROI-, observer-, absorber- and scanner-dependent factors on the reliability of CT numbers, and to provide instructions to improve the reproducibility of HU measurements in daily forensic practice.

## 2. Materials and methods

### 2.1. Materials

We scanned seven different, non-organic materials. All materials examined in this study were selected with regard to their potential forensic relevance (e.g. debris from motor vehicle accidents, shrapnel from explosions, projectiles from firearms, or jewelry for identification purposes). The materials included: rock samples (blocks of quartzite and slate, measuring 35 mm × 40 mm × 20 mm and 35 mm × 50 mm × 10 mm, respectively), glass shards from a car windshield (50 mm × 55 mm × 7 mm), aluminium (55 mm × 60 mm × 10 mm), steel (a thick steel screw, 7 mm × 7 mm × 65 mm), silver (a silver bar, 30 mm × 50 mm × 7 mm), and brass (a thick brass nail 6 mm × 6 mm × 20 mm). All objects were placed in a gelatine phantom with a gap of at least 2 cm between each object to avoid overlapping streak artifacts during CT imaging.

### 2.2. Imaging protocol

Imaging was performed on three different CT scanners: a six-slice CT scanner (Somatom Emotion 6, Siemens, Forchheim, Germany), a 64-slice CT scanner (Somatom Sensation, Siemens), and a dual-source CT scanner (Somatom Definition Flash, Siemens). The phantom was scanned at 80 kVp, always using a fixed tube current time product of 130 mAs with collimators adjusted to slice thickness. CT image reconstruction was performed with a slice thickness of 1.25 mm in increments of 0.7 mm, using bone-weighted tissue kernels. Based on the work of Bolliger et al. [14] we expected to encounter an extremely wide range of CT numbers, from less than 500 HU to more than 30,000 HU. We therefore used extended CT-scale, which allows for quantification of X-ray attenuation over an extended range, from −1000 HU to + 30,710 HU [5]. All scanners were air calibrated before image acquisition.

### 2.3. HU measurement

We performed all measurements on a picture archiving and communication system (PACS) workstation (IDS7, Sectra, Linköping, Sweden). CT numbers were measured with ROIs [17]. Each ROI covered more than one pixel and was placed in the center of the object of interest [18] (Fig. 1a). To account for object heterogeneity and irregularity in object shape we repeated HU measurements at three different levels within each object; measurements were made parallel to the long axis of the CT table at one-quarter, half and three-quarters of the length of each object. Mean HU values were calculated for each object.

### 2.4. ROI-dependency of CT numbers

To assess the influence of ROI size and shape on HU measurements, the study supervisor (who was not involved as a reader in the study) repeated all HU measurements using three different types of ROI: a large circular ROI (size adapted to object diameters); a small circular ROI (2 mm diameter); and a non-circular ROI (size and shape adapted to the individual objects) (Fig. 1b). The *t*-test was used to investigate statistically significant ROI-dependent differences between the mean HU values. *p*-Values $< 0.05$ were considered significant.

### 2.5. Absorber-dependency of CT numbers

To assess the influence of the absorbing material (i.e. heterogeneous composition and irregular shape of an object) on CT numbers, mean HU values were calculated individually for all three levels (see above) in all materials. The *t*-test was used to investigate statistically significant absorber-dependent differences between the mean HU values at each level. *p*-Values $<0.05$ were considered significant.

### 2.6. Observer-dependency of CT numbers

To assess reader-dependent differences in HU measurements we performed a reader study with five blinded readers. Each reader performed three HU measurements on every object. ROI-size and location were chosen by each reader individually. Reader-dependent mean HU values were calculated for each object. To assess intra-reader reliability, each reader repeated the measurements after a period of four weeks. The *t*-test was used to determine significant differences between the each reader as well as between both reading sessions of each reader. *p*-Values $< 0.05$ were considered significant. Intra- and inter-reader reliability were assessed using the intra-class correlation coefficient (ICC).

### 2.7. Scanner-dependency of CT numbers

To assess CT-dependent differences in CT numbers, the mean HU values of each object from each CT-scanner were compared using the *t*-test. *p*-Values $<0.05$ were considered significant.

## 3. Results

### 3.1. ROI-dependency of CT numbers

The size and shape of a ROI do not have an influence on the HU measurement. The *t*-test revealed no statistically significant difference (*p*-Values $>0.05$) between the mean HU values of the three different ROIs for each object (Table 1 ROI-dependency).

### 3.2. Absorber-dependency of CT numbers

Comparison of the mean HU values at different levels in the same objects yielded statistically significant differences (*p*-values $<0.05$) in 4/7 materials (car windshield (side), aluminium, slate, and steel). There was no significant difference in the mean HU values between the three different levels of the other materials (quartzite, silver, and brass) (Table 2, absorber-dependency).

### 3.3. Observer-dependency of CT numbers

There was no statistically significant difference between each reader's mean HU measurements and the overall mean CT number of each object (Table 3, observer dependency). The intra-class correlation coefficient for intra-reader reliability for readers one to five were 1.00 ($p < 0.001$), 0.994 ($p < 0.001$), 0.999 ($p < 0.001$), 0.999 ($p < 0.001$), and 0.929 ($p < 0.001$) respectively. The ICC for inter-reader reliability of all readers was 0.994 ($p < 0.001$).